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14. ABSTRACT
The present research sought to relate memory processes to aviation flight situation awareness (SA), to examine the effects of pilot stress on such processes, and to relate the processes to existing measure of cognitive ability for further investigation as Navy personnel classification tools. With only 1 year of funding out of the 3 applied for, the study of how stress impacts the measures was not addressed. The role of working memory (WM) capacity and long-term working memory (LTWM) skill in complex task performance was examined as a function of expertise. Experts had higher LTWM skills, suggesting that experts have a better ability to encode domain specific information into and retrieve it from long-term memory rapidly. LTWM skill and WM capacity were not correlated, suggesting they are distinct constructs. LTWM skill predicted expert SA task performance whereas WM capacity predicted novice control selection error. Experts with less WM capacity appear to compensate with increased organizational (LTWM) skill. Future state projection varied as a function of control selection accuracy for experts, but not novices. Implications for theories of memory and pilot selection are discussed.

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situation awareness, aviation, complex task performance

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INSTITUTION: Mississippi State University

GRANT TITLE: Relating Memory Processes to Aviation Flight Situation Awareness Abilities

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OBJECTIVE:

The purpose of this research was both applied and theoretical. From an applied perspective, we sought to develop new tests of cognitive abilities that would be related to later flight situation awareness (SA) performance, to relate the new measures to existing measures of cognitive ability, and to give the new measures to the Navy for further investigation as personnel classification tools. This research also sought to expand the classification tools available to identify aviators with high SA abilities. By improving such identification, the ability to match personnel skills and cognitive demands of occupations requiring SA will be enhanced.

From a theoretical perspective, this research was designed to improve our understanding of the cognitive abilities required to gain and maintain flight SA, and in so doing to provide a more precise definition of the SA construct. In addition, we intended to address the impact of stress on Navy student and expert pilot WM, LTWM, and flight SA abilities and to focus on the development and test of internal and external validity for three new measures of flight SA ability. These goals were supposed to be accomplished during years 2 and 3 of the project. Funding ended after the first year, which meant the additional goals, could not be addressed.

Background

Working Memory Capacity. Working memory (WM), defined as a limited, temporary store for processing and storing information (Baddeley & Hitch, 1974), has been studied extensively in various cognitive tasks. Individual differences in cognitive task performance are often explained by WM capacity. For example, Just and Carpenter (1992) proposed that WM capacity constrains text comprehension. Once an individual's WM capacity is reached, the lack of available processing and storage hinders the ability to use and retain new information, as well as intermediate products resulting from newly obtained information, resulting in decreased comprehension. Further research suggests a role of WM capacity in performing additional cognitive tasks, such as spatial visualization (Shah & Miyake, 1996), the ability to follow complex directions (Engle, Carullo, & Collins, 1991), and computer problem solving (e.g., Anderson & Jeffries, 1985; Doane, McNamara, Kintsch, Polson, & Clawson, 1992; Doane, Sohn, McNamara, & Adams, 2000; Sohn & Doane, 1997). According to this view, WM is thought to reside in short term memory (STM); is believed to have a fixed capacity, although individuals differ in their capacities; and an individual's WM capacity remains stable over time (e.g., Baddeley & Hitch, 1974).

Long-Term Working Memory. LTWM is a theory of a memory process that explains how individuals can extend WM capacity well beyond the proposed seven plus or minus two chunks (Miller, 1956). In LTWM theory, domain-specific knowledge and meaningful experiences are thought to increase individual ability to encode information into long term memory (LTM) and to create easily accessible retrieval structures efficiently. Ericsson and Kintsch (1995) defined a retrieval structure as an organization of meaningful data into a stable structure that can be used to encode information into and retrieve information from LTM rapidly. LTWM uses these retrieval structures as indices to situation-specific information temporarily stored in LTM. Because the information is temporarily stored in LTM, after a disruption, a task can still be completed by activating the necessary indices required to retrieve the situation-specific information. The

indices change dynamically as a function of the task at hand and the individual's expertise for that particular task.

Situation Awareness. The term situation awareness (SA) has been highlighted in the commercial and military aviation domains because of its prominent role in flight operations. Although it has been cited as a leading cause in military aviation mishaps involving human error (e.g., Hartel, Smith, & Prince, 1991; Salas, Prince, Baker, & Shreshta, 1995), there is little consensus regarding the definition of SA and little empirical evidence to support a theory of SA (Durso & Gronlund, 1999). Because of its lack of definition, SA has been criticized as being circular (Flach, 1995) and an inadequate explanation of human performance error. Although there is no consensus, most definitions can be incorporated into Endsley's (1995, 2000) information processing view. In Endsley's view, there are three separate levels of SA. Level 1 SA involves the processing of salient cues in the environment. Level 2 SA is the ability to comprehend the current situation by integrating the perceived environment with individual background knowledge and goals. Finally, Endsley's Level 3 SA is the ability to use the situation model created in Level 2 to predict the future status of the system.

<u>APPROACH</u>:

The focus of this research was on cognitive mechanisms associated with processing flight situation information, the mechanisms associated with individual differences in flight SA performance, and the changes in processing associated with experience and practice. An information processing approach was used to examine how individual differences in working memory and long-term working memory skills influence pilot flight SA performance as a function of expertise.

The first year was spent refining measures of WM, LTWM, and flight SA, and running private and military novice and expert pilots in an experiment designed to test the role of individual differences in cognitive abilities on flight SA under normal conditions. Data were collected from 52 Navy student and instructor pilots (Whiting Field in Milton, FL), with support from Lt. Cheryl Casey, USN and Ltjg. Fatolitis, USN, both of the Navy Aerospace Medical Research Lab (NAMRL). In addition, 25 student and instructor pilots of Delta State University (DSU) and local flight schools near Mississippi State University (MSU) were studied, with support from Stephanie Doane (MSU Professor of Psychology), Mark Jodlowski (MSU Ph.D. student), Catherine Sewall (MSU undergraduate), and Tommy Sledge (DSU instructor). Because of a lack of funding, the second and third-year goals - measuring the impact of stress on Navy student and expert pilot WM, LTWM, and flight SA abilities and the development and test of internal and external validity for three new measures of flight SA ability, respectively - were not addressed.

A three-phase experimental design addressed the first-year goal of refining measures of WM, LTWM, and flight SA relative to individual differences. The experiment addressed the following questions: (a) Does capacity theory account for individual differences in flight SA performance? (b) Does LTWM theory account for individual differences in flight SA performance? c) Do the capacity theory and LTWM theory account for flight SA performance differences as a function of expertise? What follows is a brief description of each of the experiments.

WM Capacity. In order to assess individual WM capacity, pilots completed an aviation-based WM capacity assessment task. This task was developed as a combined analog measure of both verbal WM (Daneman & Carpenter, 1980) and spatial WM (Shah & Miyake, 1996). In this task, pilots viewed a series of attitude indicator displays positioned in different flight orientations (see Figure 1a). Upon presentation, pilots were asked to say aloud whether the aircraft was pitched up or down. Pilots were asked to remember the orientation of the horizon line displayed on the attitude indicator and the number below the attitude indicator (see Figure 1b). Pilots first viewed a series of two attitude indicators for five trials and progressed through a series length of three and four, each containing five trials.

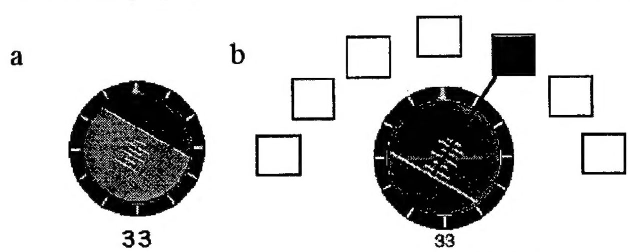

Figure 1. (a) Pitched down attitude indicator. (b) Pitched up attitude indicator that depicts the direction the horizon is pointing towards.

LTWM Assessment. To assess LTWM skill, a domain-specific piloting task similar to chess experiments (e.g., Charness, 1976; de Groot, 1965) was developed. In this task, pilots simultaneously viewed two cockpits for 40 seconds (see Figure 2a-b). One cockpit appeared on the top half of the screen, with the second cockpit displayed directly below the first. After 40 seconds elapsed, the computer presented a number and asked the pilot to count backwards aloud by threes for 30 seconds, starting from the presented number. After counting backwards by threes for 30 seconds, the computer prompted the pilots to recall the situation-specific values displayed in either the top or the bottom cockpit. Pilots used a sheet of paper containing the seven instruments with no values and a pen to fill in the situation-specific values for each instrument.

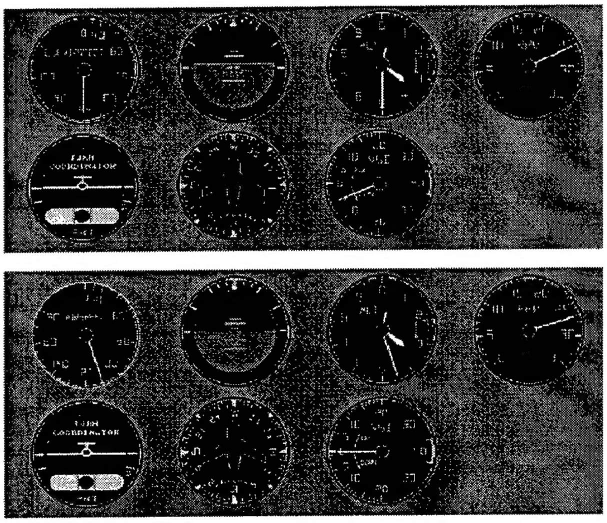

Figure 2. (a) Meaningful starting flight situation. (b) Meaningful future status after a control movement is executed.

In six of the trials, the two cockpits were related. That is, the bottom cockpit represented the future state of the aircraft 5 to 10 seconds after applying one or two control movements to the top cockpit (see Figure 2a). Three trials consisted of two unrelated cockpits; both depicting nonmeaningful flight configurations (see Figure 3a-b). Use of both meaningful and nonmeaningful situations allowed us to differentiate between retrieval originating from the use of LTWM retrieval structures and retrieval originating from the use of STM, respectively. Because WM capacity is thought to be temporary and limited in size, counting backwards by three from a given number requires processing and storage that use WM processes; thus, WM capacity could not account for pilot ability to recall cockpit information.

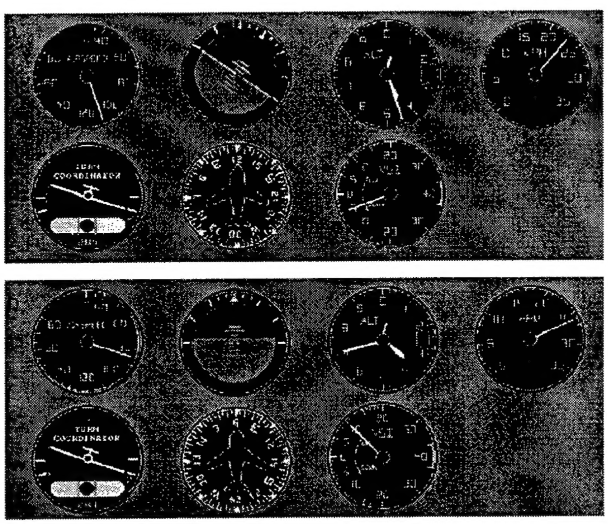

Figure 3. (a) Nonmeaningful starting situation. (b) Non-meaningful future status (instruments are in conflict in both cases).

Situation Awareness. In order to assess SA, we developed trials consisting of a series of four screens that depicted a desired flight status, a current flight situation (cockpit 1), questions about methods to achieve the desired status (control movement selection), a future flight situation intermediate to the desired status (cockpit 2), and one of two types of inquiries about a change in flight status. Figure 4 provides the names of each screen and a schematic of a trial. The first screen contained a text description of a desired heading, altitude, and airspeed, as well as a flight situation. Pilots were asked to assess the flight situation and the desired flight status specified in the goal statement, and to determine the flight control movements required to reach the goal. After selecting the control movement(s), pilots clicked "Next" to view the third screen (cockpit 2). The third screen depicted a future flight situation that resulted from the application of 1 or 2 control movements to the starting situation (cockpit 1). The pilots' task was to determine if cockpit 2 accurately depicted a flight situation that would reach the goal described in the first screen (cockpit 1) within the next 5 to 10 seconds of mentally simulated flight. The fourth screen varied with the pilots' response. If the pilots decided that the flight situation

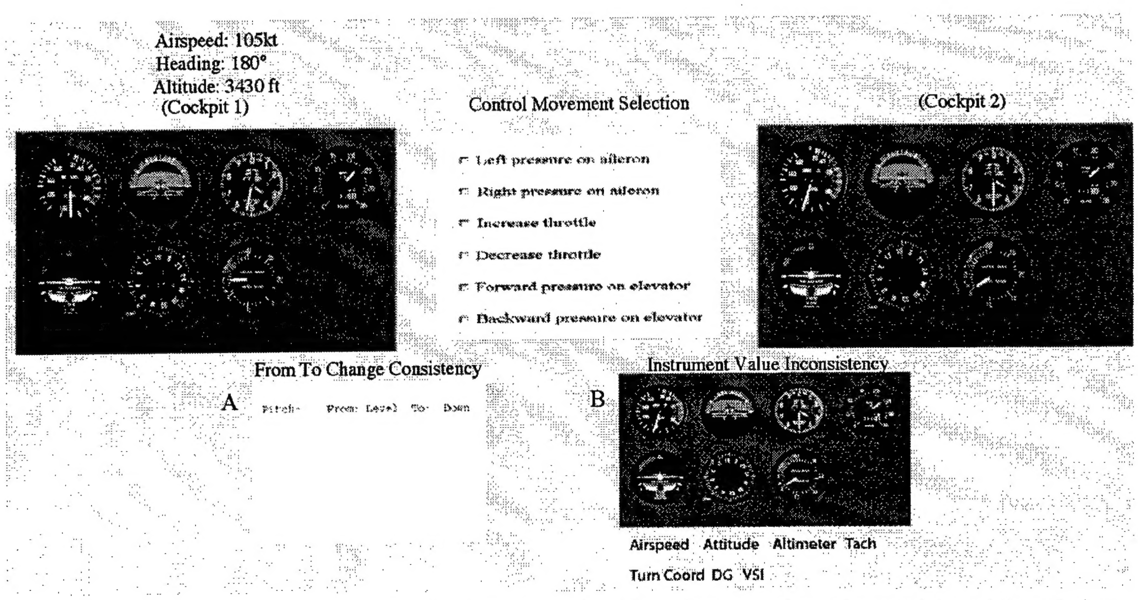

Figure 4. Flow from start to finish of an SA trial. The pilot views the cockpit and the goal statement, chooses the controls to reach the goal, views a second cockpit, and determines if the second cockpit will reach the goal in the next 5 to 10 seconds of simulated flight. Screen A or B is displayed after a consistent or inconsistent judgment, respectively.

(cockpit 2) would reach the goal, they were asked a question (screen 4a) regarding the change in flight status that took place between the starting situation (cockpit 1) and intermediate situation (cockpit 2). If the pilots decided that the flight situation (cockpit 2) would not reach the goal, they were asked to identify the instruments inconsistent with obtaining the goal (screen 4b).

The “From: To:” statements shown in the fourth screen (screen 4a) were either “consistent” or “inconsistent” with the changes that occurred between the starting situation (cockpit 1) and the intermediate situation (cockpit 2). The “From:” portion of the statement described some aspect of the starting flight situation. The “To:” portion of the statement described a change to the flight status. In consistent trials, both portions of the statement were accurate. Correctly judging a consistent statement required an accurate mental model of the effect of the control movement(s) that occurred between the two cockpits, and the application of the mental model to the specific flight situation depicted in the second screen (situation model). In other words, correct consistent judgments required an accurate mental model and situation model.

Two types of “inconsistent” statement trials were used to detect failures in mental and situation models, respectively. A mental model inconsistent statement contained an inaccurate “To:” portion. Incorrect judgment of mental model inconsistent trials as “consistent” indicates accurate memory for the starting situation (From:), but inaccurate memory of the controls that took place between cockpits or an inaccurate mental model of the effect of the control statement on flight status. A situation model inconsistent trial contained an inaccurate “From:” portion. Incorrect judgment of situation model inconsistent trials as “consistent” indicates inaccurate memory for the starting flight situation, but accurate memory of the controls that took place and an accurate mental model of the effect of the control statement on flight status.

<u>ACCOMPLISHMENTS</u> (throughout award period):

We have completed a study that examined whether WM capacity, LTWM skill, or both predicted individual differences in flight SA performance. Three experiments were designed and then developed using Authorware software. The first experiment measured WM capacity, the second experiment measured LTWM skill, and the third experiment measured two aspects of SA performance. Details about the design of each of these experiments can be found in the Approach section of this report.

Programs to extract and score the data for analysis were developed for both the WM capacity and SA programs. The LTWM experiment could only be hand scored; therefore, no extract program was created.

We were able to package and deliver the experimental software to NAMRL successfully. This demonstrates our ability to develop the software at MSU and collect data off-site without having to purchase special licenses for off-site equipment.

Data were collected from 52 U.S. Navy student and instructor pilots (Whiting Field in Milton, FL) and 25 pilots local to MSU and DSU. Navy pilot data were collected by Ltjg. Fatolitis, USN (NAMRL).

Data from the WM capacity, LTWM skill, and SA experiments were analyzed as a function of expertise. In addition, error analyses were conducted. Details of the analyses can be found in the Conclusions section of this report.

CONCLUSIONS:

One of the goals of this research was to understand the cognitive abilities required to build and maintain adequate SA better. It was important to determine if WM capacity and LTWM are distinct constructs as indicated by previous research (e.g., Sohn & Doane, 2003). The results of our experiment support this finding. For example, we found no significant correlation between the WM capacity and LTWM skill measures, suggesting that LTWM skill and WM capacity coexist. In addition, in the LTWM skill experiment, expert pilots were better able to recall meaningful situations compared to novices. This is consistent with the hypothesis that expert pilots can create and use retrieval structures (a function of LTWM). More evidence for the separability are the differences between LTWM skill and WM capacity scores prediction of future flight projection accuracy. LTWM skill predicted expert SA, but not novice. If WM capacity was the same as LTWM skill, WM capacity should have predicted performance. Consistent with the findings of Sohn and Doane, we also found an interaction between WM capacity, LTWM skill, and pilot judgments (see Figure 5). Expert pilots with higher LTWM skill appear to rely less on their WM to make judgments about the actions that took place between the starting and intermediate flight situations.

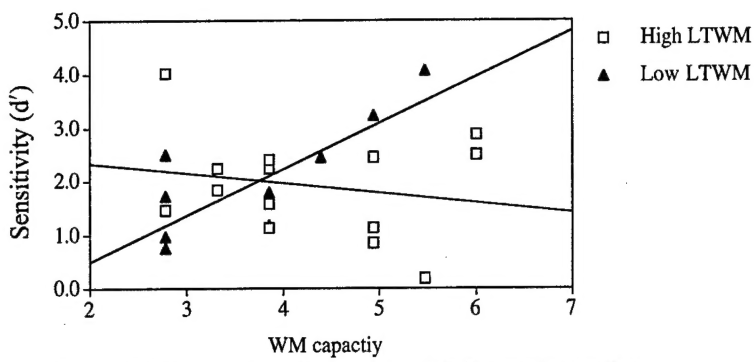

Figure 5. Relation of working memory (WM) capacity to pilot judgment as a function of long-term WM (LTWM) skill.

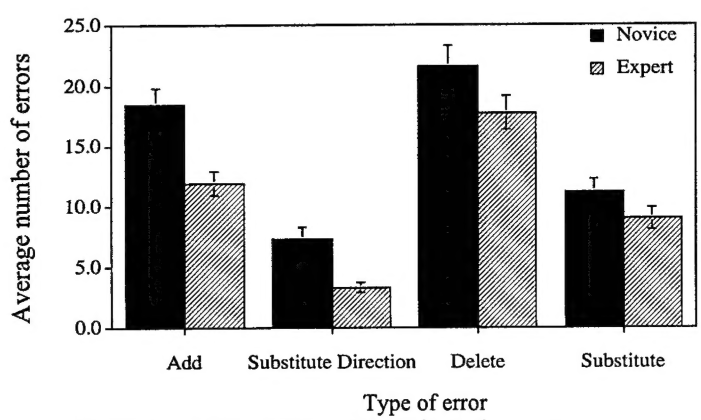

Figure 6. Average number of errors for each error type.

Given the evidence that WM capacity and LTWM skill coexist as distinct constructs, it is worthwhile to examine specific types of errors that occur as a function of expertise. The types of errors examined were related to pilot control selection. Errors were classified as one of four types. The error types include addition, deletion, substitute of direction, and substitution. Looking at Figure

6, there is a trend in the data. Novice pilots are more prone to all types of errors. The biggest differences reside in the addition and substitute of direction errors. The addition errors for novices indicate that the pilots are making simpler problems more complex whereas the experts are less likely to do so. More interesting is the finding that WM capacity predicts novice control selection error but not expert. As can be seen in Figure 7, as WM capacity scores increase, novice pilots are less likely to make a control selection error.

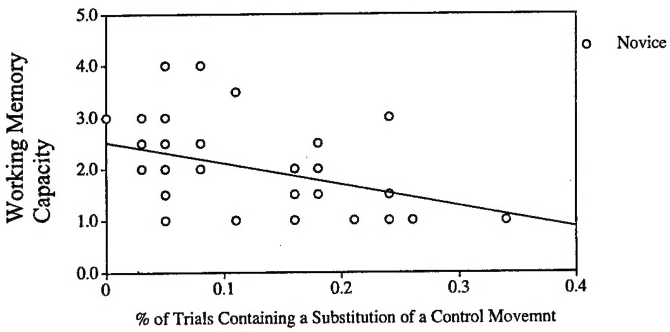

Figure 7. Relation of working memory capacity to the percentage of trials containing a substitution of a required control movement for novice pilots.

The discussion now turns to the development of SA. Further analyses of the results of the SA experiment indicate that when novices planned control movements to achieve a goal, they did not necessarily project forward the future status of the aircraft, whereas experts apparently did (see Figure 8). Recall that Endsley's (1995, 2000) information processing framework involves three levels of SA: 1) perception of cues in the environment, 2) comprehension, 3) projection of future status. Novice future status judgment accuracy was not a function of action planning accuracy. In other words, for novices, Level 2 SA did not predict Level 3 SA. In contrast, expert future status judgment accuracy (Level 2 SA) was a function of action planning accuracy (Level 3 SA). Our results suggested that novices were vulnerable to failures in Level 3 SA regardless of their Level 2 SA status. In addition, the findings suggested that it may be possible to predict Level 3 SA failures for experts based on their action planning. One interpretation of these results is that novice and expert pilots process action plans differently; expert action planning necessarily involves Level 3 SA and novice action planning does not.

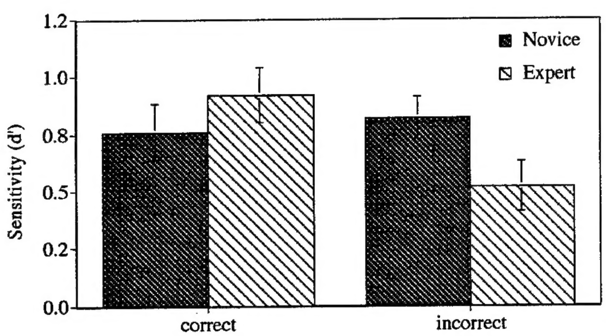

Figure 7. Accuracy of future judgments based on selecting the correct versus incorrect (adequate vs. inadequate SA) controls as a function of expertise.

In summary, it appears that both WM capacity and LTWM skill have the potential to identify individuals who are more likely to obtain adequate levels of SA. In addition, because WM capacity predicted novice action plan errors, it may be possible to facilitate training and performance by designing systems that support minimal WM demands. With respect to LTWM skill, it may be possible to train for better organizational skills. One possible test is to see how well individuals organize common material. People with better organizational skills may be more likely to develop retrieval structures that will facilitate building and maintaining adequate SA.

SIGNIFICANCE:

In the 21st century, Navy aviators will be asked to perform tasks in more complex and dynamically changing environments than ever before in order to meet operational requirements (NPRST Sailor 21 document). Many current and future Navy aviation jobs demand the ability to build and maintain awareness of a dynamically changing flight situation based on information presented in visual cockpit displays. For example, aviation pilots must perceive and comprehend indications of their aircraft status, such as airspeed, heading, and altitude in order to achieve and to monitor progress toward flight goals. The ability to monitor

instruments, perform actions, and comprehend a dynamically changing situation is required in many Navy jobs, both air and sea. For example, air traffic controllers, tactical coordinators, and submarine and ship operators must build and maintain awareness of their operational situations. Thus, situation awareness abilities enable sailors to perform in a broad range of Navy jobs.

Each of the Navy jobs described above requires high situation awareness abilities (Endsley, 1995, 2000), and recent research suggests that individual differences in cognitive abilities predict flight situation awareness performance (e.g., Sohn & Doane, 2003). Identifying recruits with the cognitive abilities that enable high situation awareness performance would facilitate their selection and classification into these occupations and others in which successful performance depends on situation awareness skills (Alderton, 1989; Sohn & Doane).

The focus of this research was on developing new measures of three components of cognitive abilities that have been shown to support task performance on flight situation awareness tasks (Sohn & Doane, 2003); working memory capacity (e.g., Daneman & Carpenter, 1980; Just & Carpenter, 1992; Shah & Miyake, 1996), long-term working memory skills (e.g., Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995; Kintsch, 1998), and the ability to reason about sequence-dependent events or "event reasoning"(Doane & Sohn, 2001; Durso & Gronlund, 1999). Computer administered tests were developed for each processing ability and were tested for their predictive validity for flight situation awareness task performance. Thus, the first year goal of providing new measures of flight situation awareness abilities and relating them to later learning and performance was achieved. Unfortunately, because of a lack of funding, the measures were not further developed, and the impact of stress on these measures was not examined. Therefore, we were unable to improve upon situation awareness ability assessment, and we were unable to provide new and useful classification tools that would benefit a broad spectrum of Navy jobs that require situation awareness abilities.

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REFEREED PUBLICATIONS (for total award period):

1. Doane, S. M., Sohn, Y. W., & Jodlowski, M. J. (in press). *Pilot Ability to Anticipate the Consequences of Flight Actions as a Function of Expertise.* Human Factors.
2. Jodlowski, M. T., Doane, S. M., & Sohn, Y. W. (2002). Mental models, situation models, and expertise in flight situation awareness. *Proceedings of the 2002 Annual HFES Conference*, 377-381.
3. Jodlowski, M. T., Doane, S. M. (in press). Event reasoning as a function of working memory capacity and long term working memory skill. *Proceedings of the 2003 Annual Cognitive Science Society Conference.*
4. Jodlowski, M. T., Doane, S. M. (in press). The impact of pilot expertise and action planning on future state projection ability. *Proceedings of the 2003 Annual HFES Conference.*

BOOK CHAPTERS, SUBMISSIONS, ABSTRACTS AND OTHER PUBLICATIONS (for total award period):

1. Jodlowski, M. T. (2002). Mental models, situational models, and expertise in flight situation awareness. *First Annual Mississippi State University Department of Psychology Research Forum, Mississippi State, MS.*
2. Jodlowski, M. T. (2003). Event Reasoning as a Function of Working Memory Capacity and Long Term Working Skill. *Second Annual Mississippi State University Department of Psychology Research Forum, Mississippi State, MS.*

REFERENCES:

Alderton, D. L. (1989). *Development and evaluation of integrating details: A complex spatial problem solving test* (NPRDC Technical Report 89-6). San Diego: Navy Personnel Research and Development Center.

Anderson, J. R., & Jeffries, R. (1985). Novice LISP errors: Undetected losses of information from working memory. *Human-Computer Interaction, 1*, 133-161.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47-89). New York: Academic Press.

Charness, N. (1976). Memory for chess positions: Resistance to interference. *Journal of Experimental Psychology: Human Learning and Memory, 2,* 641-653.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19,* 450-466.

de Groot, A. D. (1965). Thought and choice in chess. The Hague, Netherlands: Mouton.

Doane, S. M., McNamara, D. S., Kintsch, W., Polson, P., & Clawson, D. M. (1992). Prompt comprehension in UNIX command production. *Memory & Cognition, 20,* 327-43.

Doane, S. M., Sohn, Y. W., McNamara, D. S., & Adams, D. (2000). Comprehension based skill acquisition. *Cognitive Science, 24,* 1-52.

Doane, S. M., & Sohn, Y. W. (2001). *Measuring flight situation awareness: Effects of working memory, pilot expertise, and situational complexity.* Manuscript submitted for publication.

Durso, F. T., & Gronlund, S. D. (1999). Situation awareness. In F. T. Durso, R. Nickerson, R. Schvaneveldt, S. Dumais, S. Lindsay, & M. Chi (Eds.), *The handbook of applied cognition* (pp. 283-314). New York: Wiley.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32-64.

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness. In M. R. Endsley & D. J. Garland (Eds.), *Situation awareness analysis and measurement* (pp. 3-32). Mahwah, NJ: Erlbaum.

Engle, R. W., Carullo, J. J., & Collins, K. W. (1991). Individual differences in working memory for comprehension and following directions. *Journal of Educational Research, 84*, 253-262.

Ericsson, K. A., & Delaney, P. F. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 257-297). New York: Cambridge University Press.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*(2), 211-243.

Flach, J. M. (1995). Situation awareness: Proceed with caution. *Human Factors, 37*(1), 149-157.

Hartel, C. E. J., Smith, K., & Prince, C. (1991). *Defining air crew coordination: Searching mishaps for meaning.* Paper presented at the Sixth International Symposium on Aviation Psychology, Columbus, OH.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99,* 122-149.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition.* New York: Cambridge University Press.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Salas, E., Prince, C., Baker, D. P. & Shreshta, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors, 37*(1), 123-136.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125*(1), 4-27.

Sohn, Y. W., & Doane, S. M. (1997). Cognitive constraints on computer solving skills. *Journal of Experimental Psychology: Applied, 3,* 288-312.

Sohn, Y. W., & Doane, S. M. (2003). Role of working memory capacity and long term working memory skill in complex task performance. *Memory & Cognition, 31*(3), 458-466.